Stratospheric Observatory for Infrared Astronomy

SOFIA

safire

Submillimeter and Far Infrared Experiment

SSSC Meeting
July 23, 2001

Dominic Benford, Instrument Scientist

Harvey Moseley, PI

A NASA Origins Mission

Developed and operated for NASA by USRA

All the Answers, Up Front

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- Can SAFIRE be ready at first light?

  Yes! SAFIRE will be ready and ground-tested at the CSO by SOFIA first light.

- What compelling science can SAFIRE deliver with first light performance?

  SAFIRE will deliver full science capability at first light:

  - *Powering of Ultraluminous Infrared Galaxies*
  - *ISM cooling from CII (158μm) & other FIR fine structure lines*
  - *Evolution of Matter in Universe*
  - *Diagnostics of Active Galactic Nuclei*
  - *Star formation in the Galaxy and out to high redshifts*

How Can SAFIRE be Ready by 2004?

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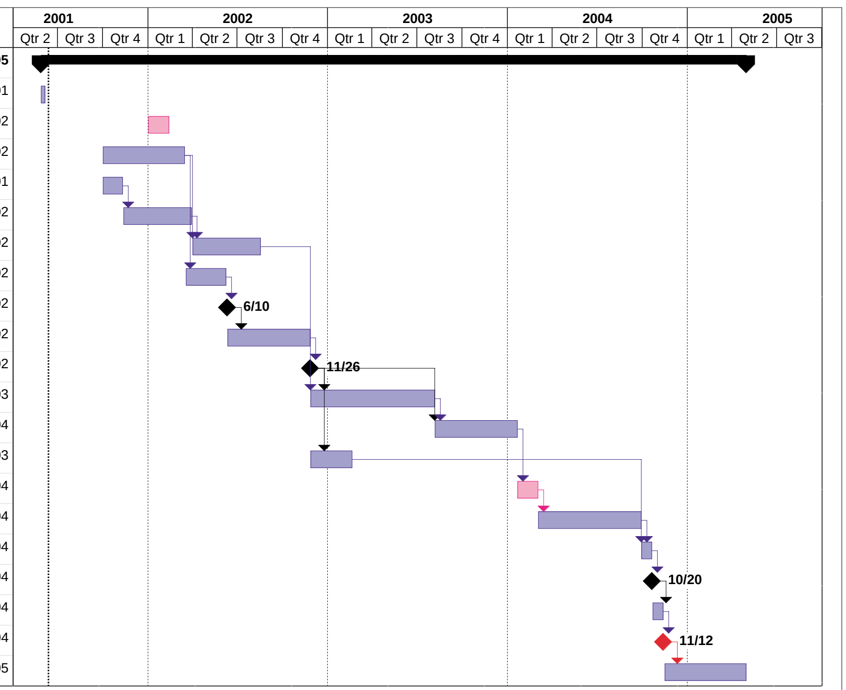
- Aggressive demonstration of technology building blocks as we go; risks retired early
- Reliance on GSFC resources, extensive leveraging of other projects (FIBRE, SPIFI)
- Funding continued at original request w/gap funding; *SAFIRE's cost-at-complete has not grown*

ID	Task Name	Duration	Start	Finish
1	**SAFIRE (Moseley, NASA/GSFC)**	**1025d**	**5/28/01**	**4/29/05**
2	SAFIRE Prototype at CSO (FIBRE Run 1	6d	5/28/01	6/4/01
3	SAFIRE Prototype at CSO (FIBRE Run 2	30d	1/1/02	2/11/02
4	SAFIRE Prototype Array (SPIFI) Fab	120d	10/1/01	3/15/02
5	Lab tests of SAFIRE Cryostat	30d	10/1/01	11/9/01
6	Cryo tests of SAFIRE Mechanisms	100d	11/12/01	3/29/02
7	Prototype array test in cryostat	100d	4/1/02	8/16/02
8	PADR Prep	60d	3/18/02	6/7/02
9	SAFIRE PADR	1d	6/10/02	6/10/02
10	CADR Prep	120d	6/11/02	11/25/02
11	SAFIRE CADR	1d	11/26/02	11/26/02
12	Instrument final fab	180d	11/27/02	8/5/03
13	SAFIRE Instrument I&T	120d	8/6/03	1/20/04
14	SAFIRE Airworthiness deadlines	60d	11/27/02	2/18/03
15	SAFIRE ground test at CSO	30d	1/21/04	3/2/04
16	SAFIRE Flight Prep	150d	3/3/04	9/28/04
17	Deliver SAFIRE to SSMOC	15d	9/29/04	10/19/04
18	ORR for SAFIRE	2d	10/20/04	10/21/04
19	SAFIRE ground test at SSMOC	15d	10/22/04	11/11/04
20	SAFIRE First Light	1d	11/12/04	11/12/04
21	SAFIRE Certification	120d	11/15/04	4/29/05



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SAFIRE Prototype FIBRE

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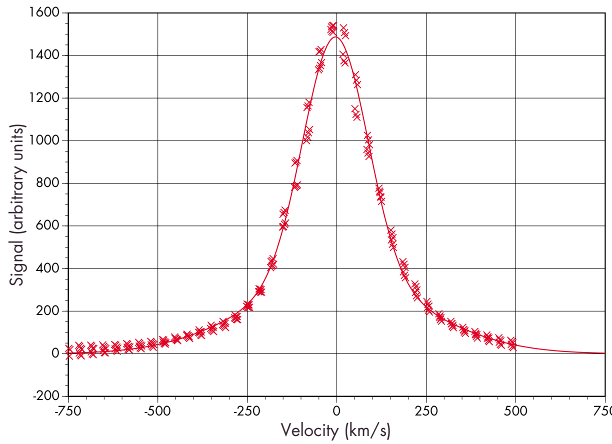
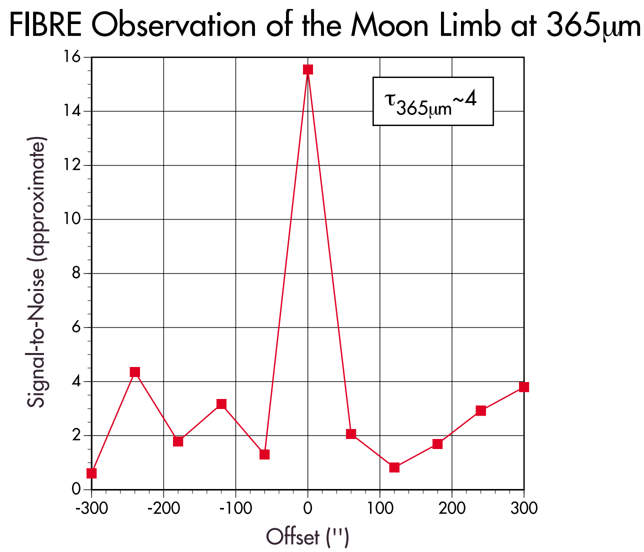
- In order to mitigate technology risks, the SAFIRE team has developed a prototype instrument called FIBRE (Fabry-Perot Interferometer Bolometer Research Experiment).
- FIBRE is a ground-based spectrometer designed to demonstrate the key technologies for SAFIRE: superconducting transition edge sensor (TES) bolometers, SQUID multiplexed amplifiers, high speed data acquisition hardware, and a cryogenic Fabry-Perot.
- FIBRE achieved first light at the Caltech Submillimeter Observatory on June 2, 2001.

FIBRE on the CSO



Spectrum of LO source



Detection of the Moon

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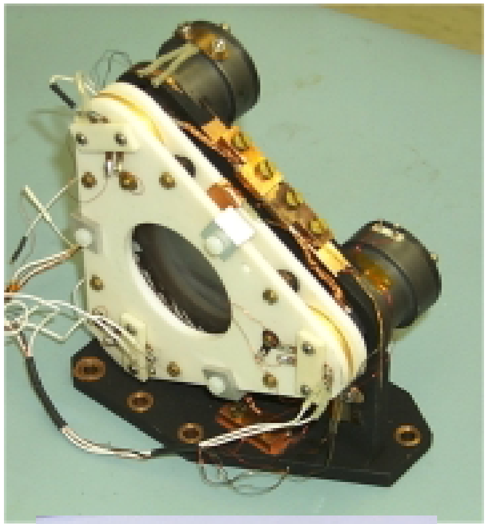
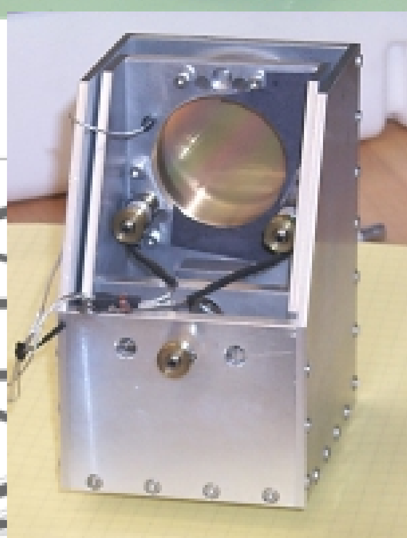
SAFIRE Parts

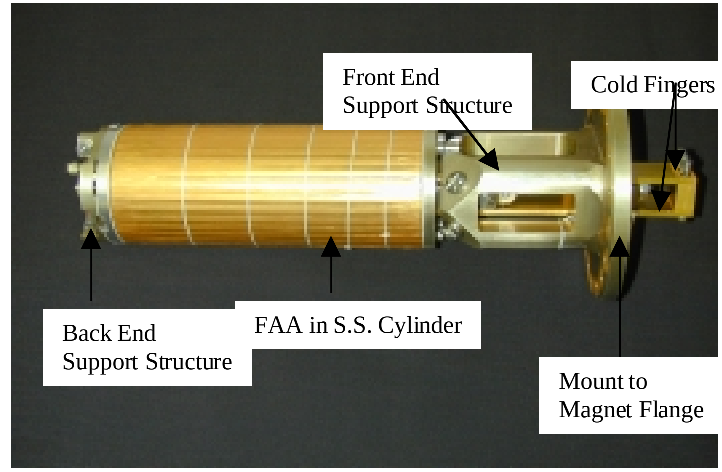
Fabry-Perots

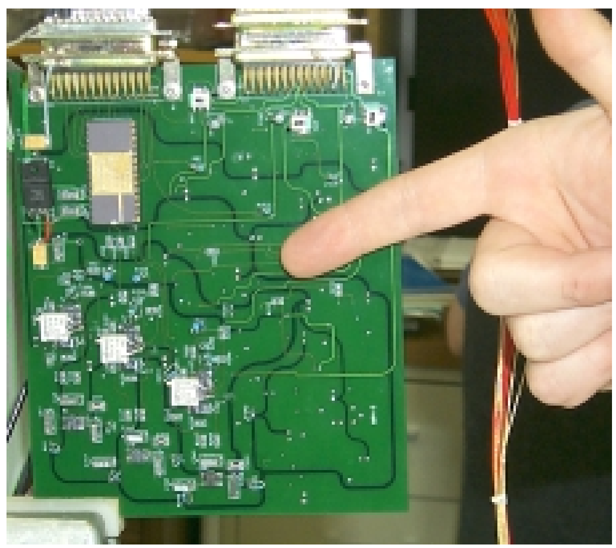




Cryostat

ADR (salt pill)





Fabry-Perot control board

Part of Bolometer Readout Electronics

Sean's Status as of May 2001

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SAFIRE Development Elements

Subsystem	B	Cost	Status	Risk	Mitigation
Cryostat					
ADR electronics					
TES bolometers					Proto-type
TES electronics					Proto-type
Optics design (frozen)					
Spectrometer optics/mechanics					
Software (operations)					
Software (data reduction)					CSO Obs.

With the successful deployment of the SAFIRE prototype to the CSO:

- TES bolometers with SQUID multiplexer readouts have been validated
- End-to-end testing (including software) has been performed.

SOFIA Science Missions

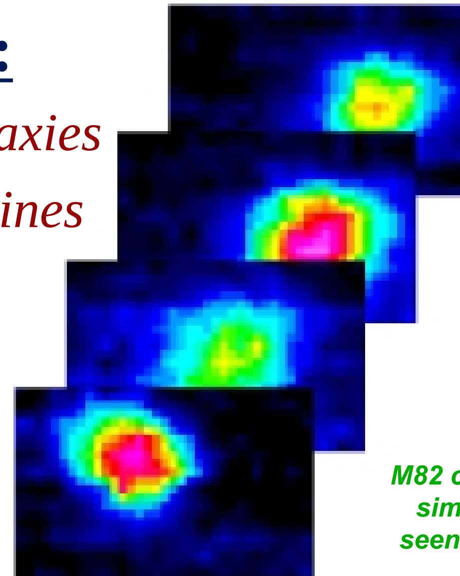
Circumstellar Disks	FORCAST
Galactic Center	FORCAST, **SAFIRE**, HAWC, AIRES
Powering of ULIRGs	**SAFIRE**, FIFI-LS, HAWC, AIRES
Extragalactic Star Formation	**SAFIRE**, FIFI-LS, HAWC, AIRES
Transits of Extrasolar Planets	HOPI
Planets (e.g., Gas Giants, Titan, Pluto/Charon)	HOPI, **SAFIRE**
Deuterated Hydrogen	GREAT
CII cooling of the ISM	GREAT, **SAFIRE**, FIFI-LS, CASIMIR
Evolution of Matter in the Early Universe	HAWC, **SAFIRE**, AIRES
Active Galactic Nuclei	HAWC, **SAFIRE**, AIRES
Spectroscopy of protostars	CASIMIR, GREAT, **SAFIRE**
ISM Chemistry	CASIMIR, GREAT
Infall/Outflow around YSOs	AIRES, CASIMIR, GREAT, FIFI-LS
SNR Impact on Molecular Clouds	AIRES, CASIMIR, GREAT, FIFI-LS
Planet Formation	EXES
Water vapor in molecular clouds	EXES, CASIMIR, GREAT

SAFIRE will significantly impact studies in half of SOFIA's key areas!

SAFIRE: Far-IR Imaging on SOFIA

<u>**SAFIRE High Priority Science Goals:**</u>

- *Powrering of Ultraluminous Infrared Galaxies*
- *ISM cooling traced by FIR fine structure lines*
- *Evolution of Matter in Universe*
- *Diagnostics of Active Galactic Nuclei*
- *Star formation in the Galaxy*
- *Star formation out to high redshifts*



M82 channel map simulation as seen by SAFIRE

(D. Benford)

<u>SAFIRE's unique capabilities enable these science goals</u>

- Detecting highly redshifted CII (158µm) from ULIRGs such as Arp220 or Mrk231
- Measuring line emission from galaxies at λ>100µm
- Imaging at submillimeter wavelengths; imaging spectroscopy (e.g., Galactic center)

SAFIRE: Far-IR Imaging on SOFIA

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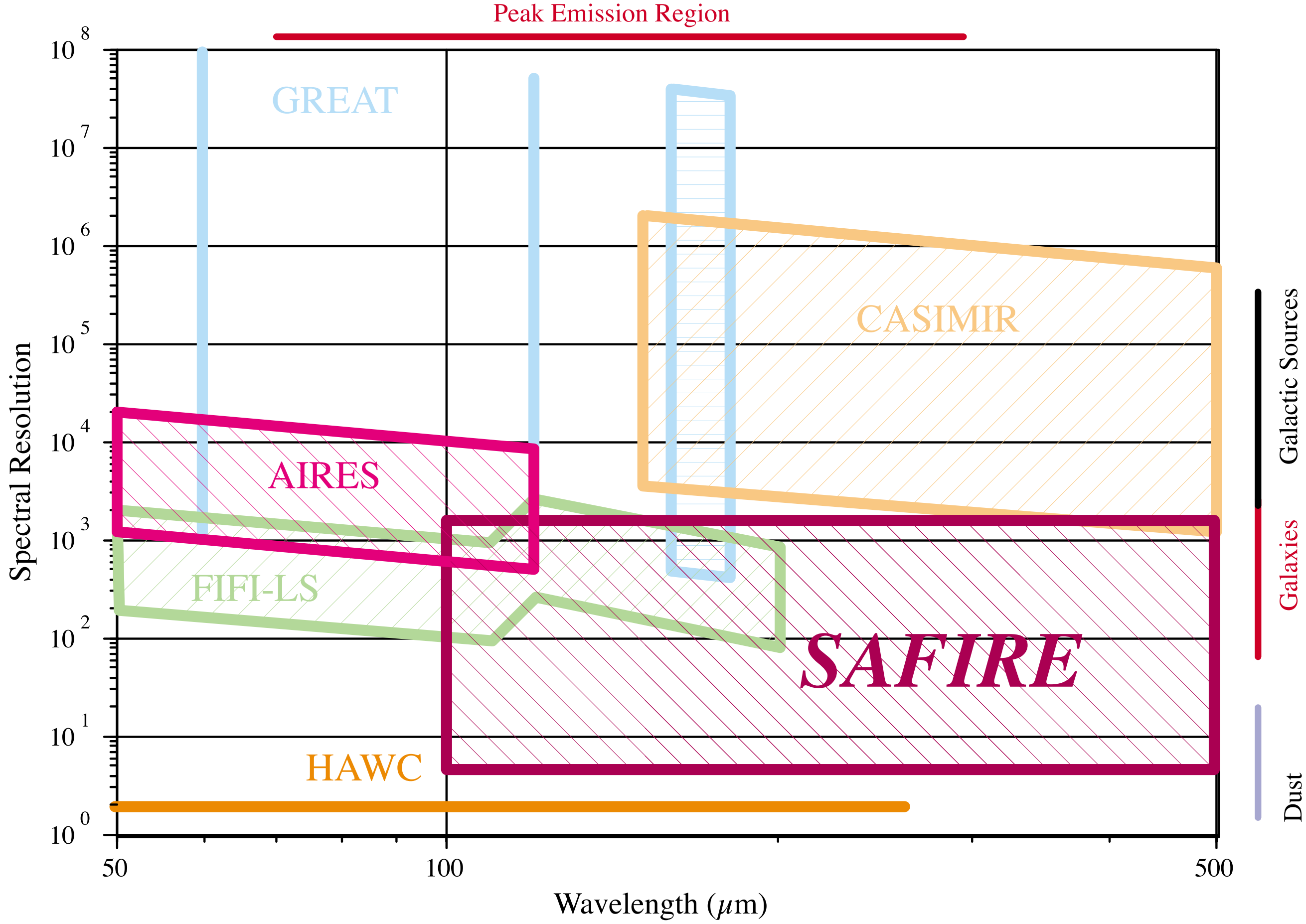
SAFIRE fills a unique, crucial role for SOFIA:

- Far-IR wavelengths (145µm–655µm) (no SIRTF equivalent)
- Moderate velocity resolution (150km/s) (no SIRTF equivalent)



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SAFIRE: Far-IR Imaging on SOFIA

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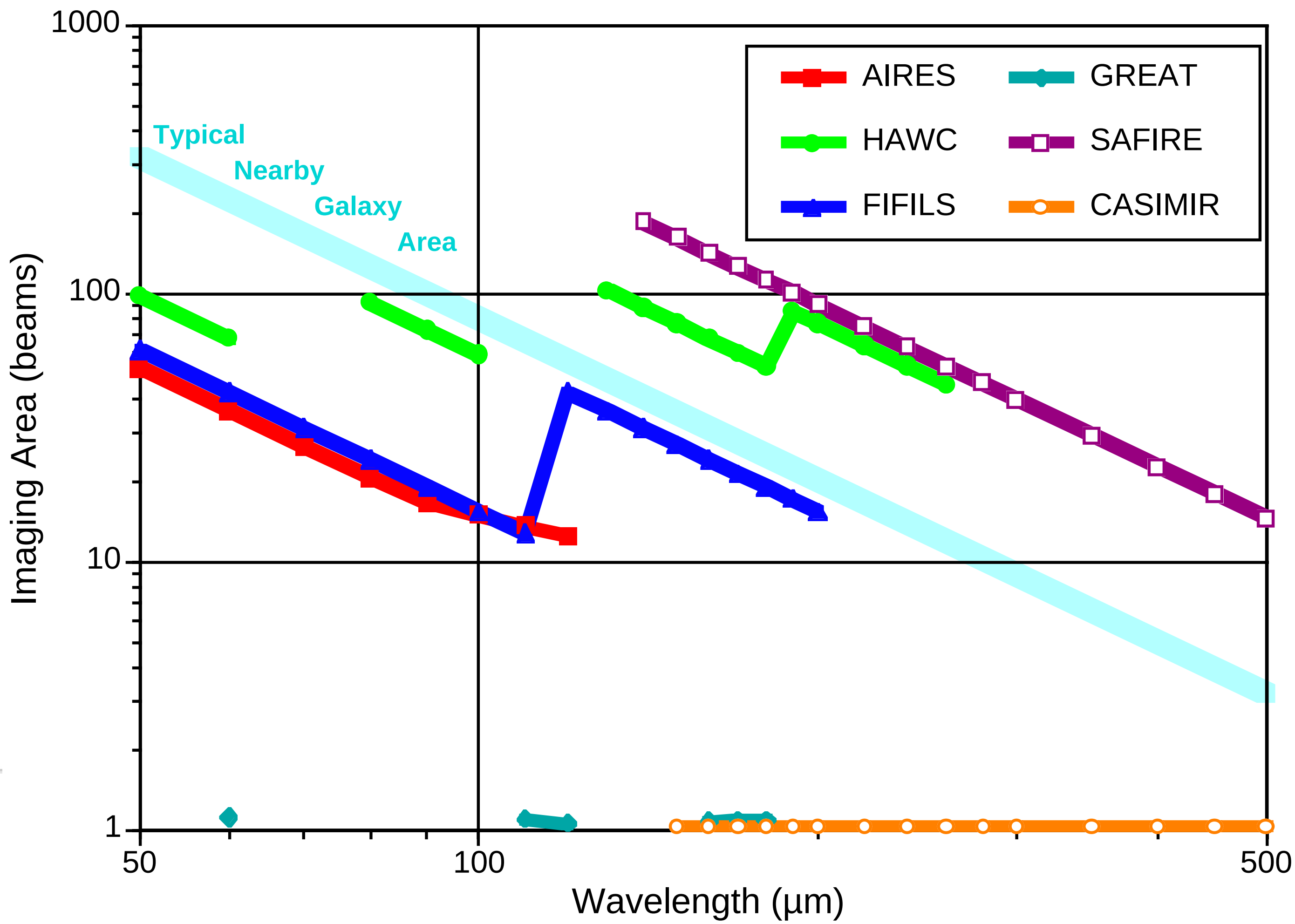
SAFIRE fills a unique, crucial role for SOFIA:

- Only SOFIA instrument with imaging capability at λ>250μm



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Far-IR Lines as Science Tools

Many fine-structure and molecular-transition lines serve as probes of the physical properties of the ISM of the Milky Way and other galaxies:

- [OI], [SiII] lines probe the physical conditions of gas in PDRs.
- [NIII], [SIII], and [OIII] line pairs are excellent probes of HII region densities.
- [NII] lines trace the warm ionized medium.
- [CII] line traces PDRs, atomic clouds, and warm ionized medium.
- [NII]/[NIII], [SIII]/[OIII], [NeIII]/[OIV]/[NeV] ratios give the effective temperature of stellar or AGN UV radiation fields.
- [SI], [SiI], [SiII] and [FeI] lines indicate the presence of dissociative J-shocks.
- High-*J* CO rotational lines trace shocked gas found in warm dense gas of PDRs.
- OH lines trace shocked gas in cool dense gas.
- H_2 rotational lines probe the mass of warm molecular clouds.
- OH, CH, and NH_3 together constrain molecular cloud chemistry.
- [CI] traces star formation, atomic clouds.

Redshifted Fine-Structure Line Emission

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- The brightest emission lines from star forming galaxies are the fine-structure lines of common species:

  [CII] 158 μm, [OI] 63 and 145 μm,

  [NII] 122 and 205 μm, [OIII] 52 and 88 μm

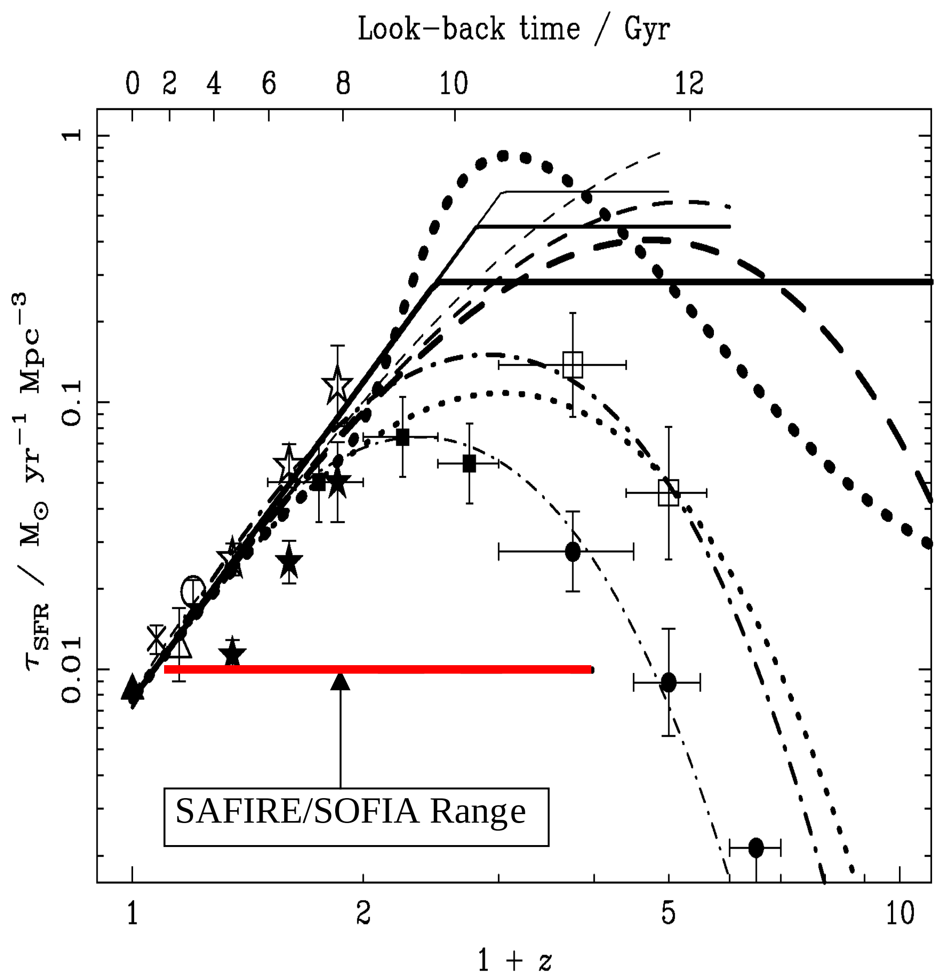
- Dominate the cooling of several phases of the ISM, comprising much of the mass:

  ELD HII regions, atomic clouds, PDRs

- Probes of: ISRF (hardness and intensity), ISM density, mass, metallicity
- The brightest of these lines is the [CII] line which typically accounts for ~ 0.1 to 1% of the far-IR luminosity of star forming Galaxies.

The [CII] Line and Star Formation in the Early Universe -- I

- Far-IR continuum is a diagnostic of total luminosity for dusty galaxies
- Strong [CII] is associated with star formation
- Can survey [CII] in the distant Universe using SAFIRE in the critical redshift range between 1 and 3. It is here that the greatest change star formation per unit in co-moving volume occurs.
  - What powers the SCUBA galaxies?
  - How strong are starbursts in the early Universe?



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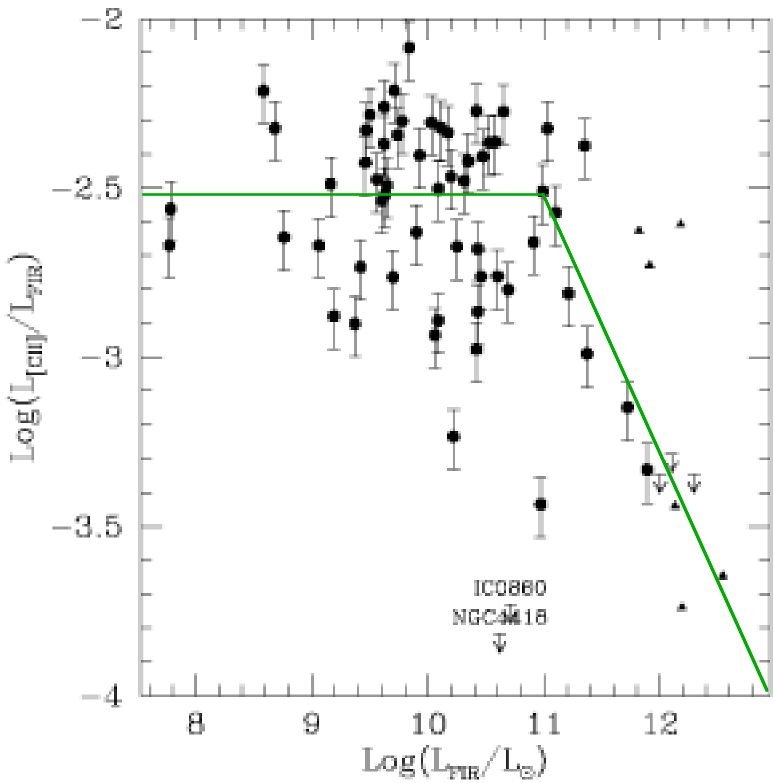
The [CII] "Deficit" in Warm Dust Galaxies - I

- There is a tendency for higher luminosity sources to have a smaller [CII] line to far-IR continuum ratio.
- *This change in line ratio is the physics* --- to first order, the ratio reflects the strength of the ambient interstellar radiation field, G_o.
- SAFIRE can trace this line in ULIRGs out to z>0.3

Malhotra et al. 2001



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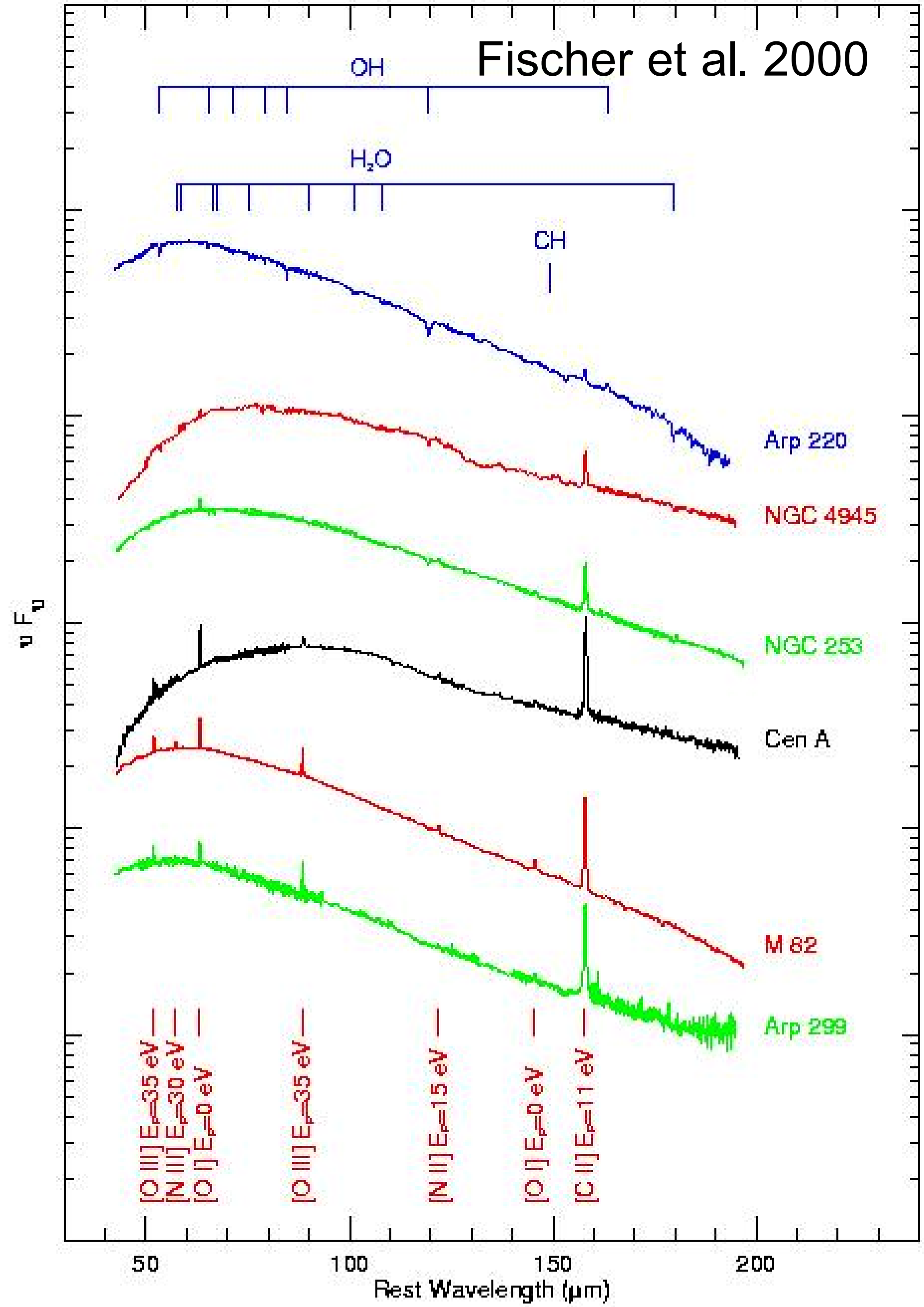
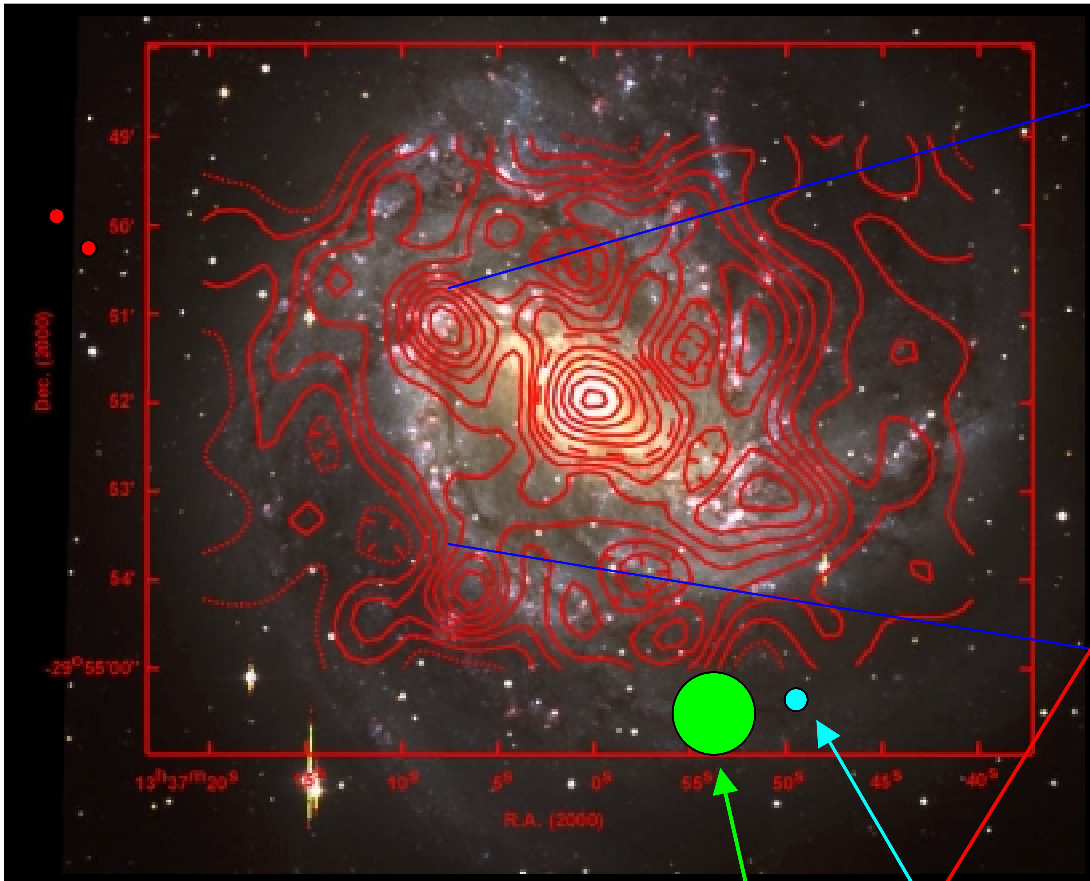
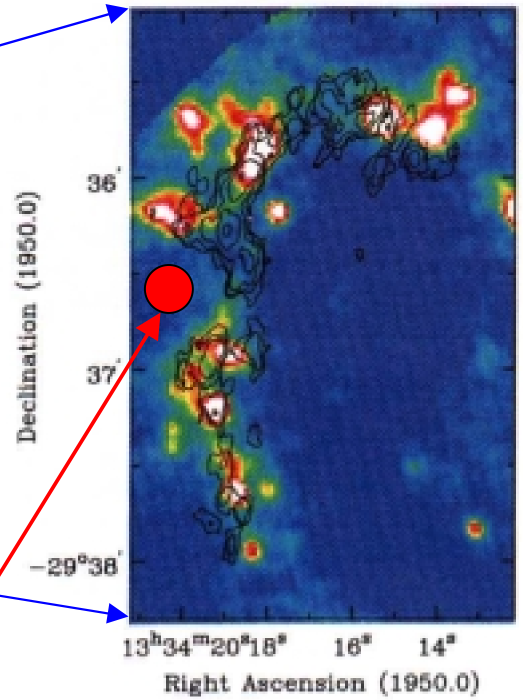
ISO Observations of IR Bright Galaxies

- Far-IR fine-structure lines prominent for most IR bright galaxies
  - trace radiation fields
  - trace gas properties
  - trace abundances
  - dominate gas cooling
- F-S lines weak in Arp 220
  - molecules very strong!
  - [CII] 10 times weaker than expected
- *Notice that Arp 299 is bright*
  Also a ULIRG!
- Less than half of the ULIRG have severe (> 2 X) [CII] deficits



SAFIRE Imaging of Galaxies: M83





CO (1-0) Map Overlayed on false-color HI (Rand Lord, & Higdon 1999

FIFI/KAO [CII] Map: 55" Beam (Geis et al. in prep.)

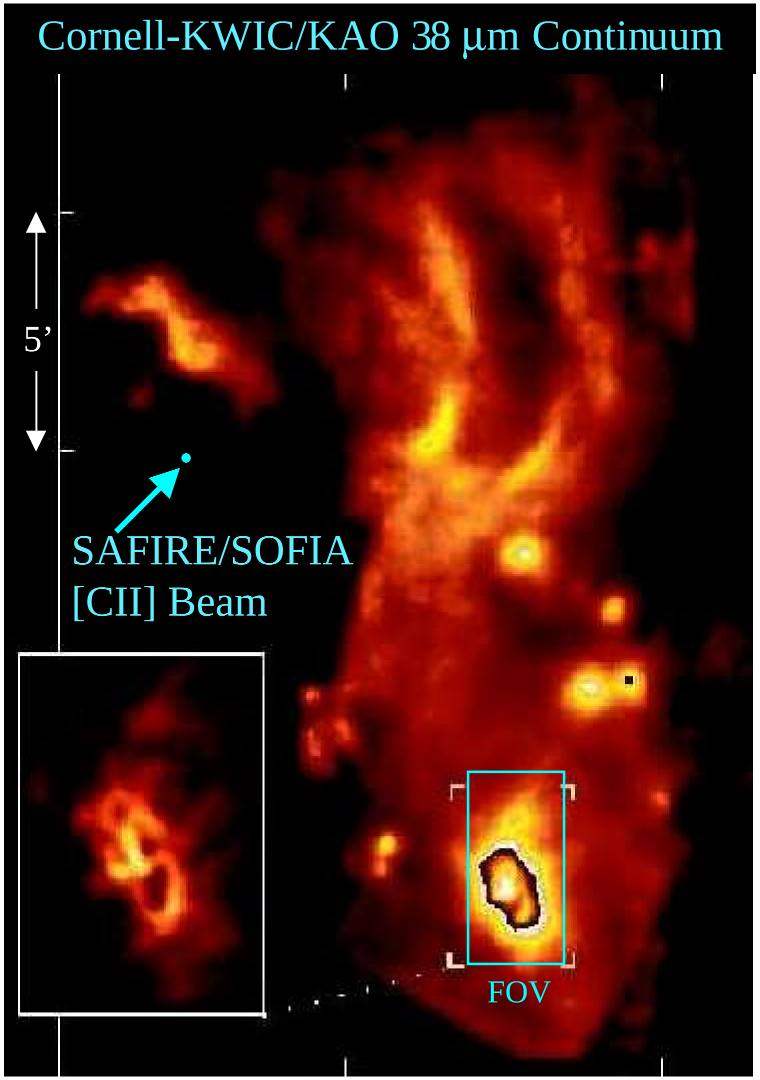
SAFIRE/SOFIA 16" [CII] Beam

SAFIRE Will Easily Resolve the [CII] Line Emission from Spiral Arms ⇔ Star Formation in Spiral Galaxies

SAFIRE Observations of the Galactic Center - I

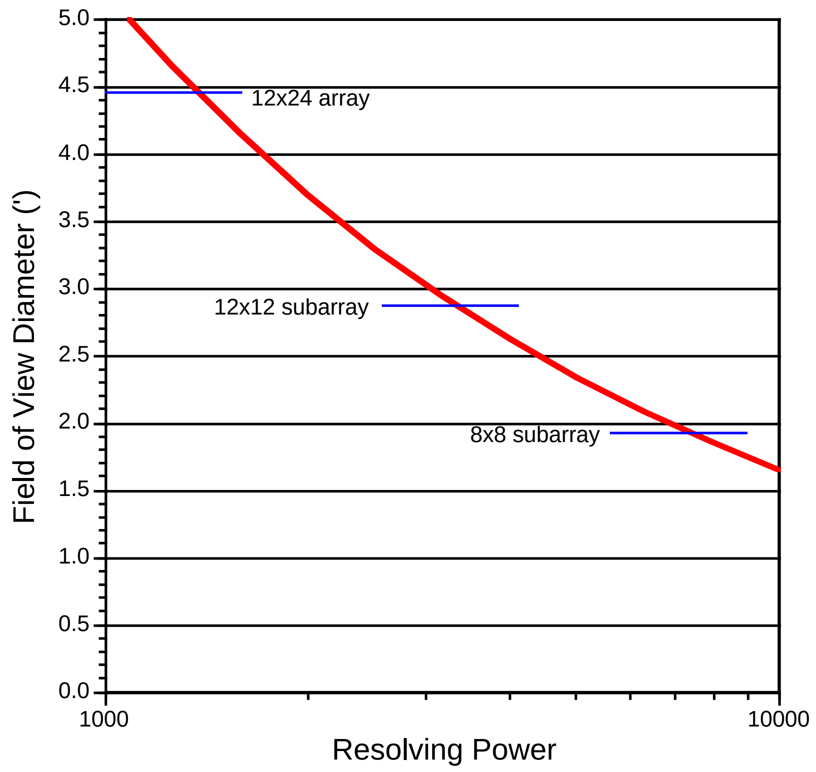
SAFIRE can map the entire thermal and nonthermal arches region in a wide variety of spectral lines

- Arches: Where are the stars?
  - –Mapping in [CII], [OI], [NII], and mid-J CO lines locates sources of excitation
- Sickle: Shocks
  - –Mid to high J CO, and HCN excited near shock
- Circumnuclear ring: what is the mass & size?
  - – [CI] line ratios trace gas column density and temperature, but are insensitive to gas density
- Circumnuclear ring: Where is the gas reservoir that replenishes the ring?
  - – [CII] & [OI] 145 μm lines trace gas excitation & kinematics at high resolution in large region
- Circumnuclear ring: What excites molecular line emission from the ring: radiation or shocks?
  - –Mid and high-J CO line ratios, OH 163 μm line can be used to determine



SAFIRE's Extended Capabilities - I

- Wavelength range can be increased to include λ≥100μm, permitting detection of additional lines (e.g., NII)
- Spectral Resolution can be increased at the price of reducing available field of view. R=10,000 spectroscopy should be possible with a 2' diameter FOV.
- Scale change may be possible to optimize detector performance



These options should be available with negligible additional cost.

SAFIRE's Extended Capabilities - II

- Wavelength range could be increased to include certain wavelengths in the $50\mu m \leq \lambda \leq 205\mu m$ range, permitting detection of additional lines (e.g., OI at 63μm)
- Scale change would be considered to optimize detector performance, provide $R \sim 10^4$ spectroscopy
- Narrowband filters would be used for some number of lines over the 50μm-200μm range (e.g., OI, CII, NII lines); only useable in Milky Way or nearby galaxies
- These changes would require configuration changes in the cryogenic system (no mechanisms, separate runs)

This capability should be available with low additional cost.